Information Access of Approach Navigation for Nonlinear Autonomous Systems

PROGRESS REPORT 1

October 20, 1997 - February 06, 1998

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March 4, 1998

Contract no:	N00014-97-C-0336
Title:	Information Access of Approach Navigation for Nonlinear Autonomous Systems
PI:	Björn Jawerth, Summus, Ltd.
Period:	October 20, 1997 - February 6, 1998.

1 Basic Information

The following is a progress report for worked performed under the ONR's ***Information Access of Approach Navigation for Nonlinear Autonomous Systems*** contract over the period 20 October 1997 through 6 February 1998. Summus, Ltd. is a small business located at **950 Lake Murray Blvd., Irmo, SC 29063**. Funds expended during this period were $84,959.58. For further information please contact the principal investigator and primary business contact for this effort **Dr. Björn Jawerth, 803-781-5674 (tel), 803-781-5679 (fax), bj@summus.com**.

2 Overview

This initial phase of the effort is focused on developing and understanding appropriate definitions, and related tools and methods, applicable to the problem of identifying, classifying, tracking, and acting on visual information, potentially aided by physical information, in highly dynamic environments. We focus on defining elemental aspects of shape, shape evolution, and methods for representing and sampling visual information spaces. Our approach to defining these elemental aspects focuses on identifying computationally efficient methods and to investigating the relationships between elements and objects in the information space. Further we investigate methods that apply a hierarchical segmentation, assignment and processing of information. This process establishes a foundation for the objectification of the underlying properties in the information space that is consistent with the capabilities provided by the methods and tools identified for extraction, enhancement, or verification of the information properties and objects.

Ultimately, this should lead to an information alphabet that allows rapid identifi-

cation objects within the information environment, as well as providing a method to define many layers of properties which may be assigned to an object. As applied to this project, the alphabet and the associated syntax for building objects will be used to define object in an invariant way, thus leading to a reliable way to gather, fuse, and transmit information sources. This formulation of the information environment will also be applicable to other object related activities, such as, compression, noise reduction, and enhancement, and thus, will provide a computationally efficient foundation for various information processing activities in highly dynamic environments, such as those anticipated for UCAV or hypersonic missile systems.

Specifically, we have investigated the following methods and tools for application to the central focus of this project.

- Shape description
  - Voronoi, multiscale representations
  - α-shapes
  - superresolution
- 3D-2D
- nonregular sampling
  - motion detection
  - new gaze-based representations
  - collision avoidance

3 Technical Information

3.1 Shape description

One of most important image processing tasks for an "intelligent" fully autonomous, or even semi-autonomous, UAV is to automate shape description. At the same time, quantifying shape has historically turned out to be one of the more challenging problems. Fundamentally, this can be traced back to the fact that shape requires a higher level description while most of our mathematical tools deal with low level processing.

The higher level description belongs more to the area of topology while the low level uses classical differential geometry and harmonic analysis/PDE. Still, some significant progress has recently been made by using nonlinear diffusion equations and so called multiscale analysis. As part of this effort we are investigating and developing several procedures for shape description.

3.1.1 Voronoi, multiscale representations

The nonlinear diffusion equation approach to shape description is closely related to Voronoi tesselations. Using the Voronoi interpretation of the solutions to the diffusion equations, it is possible to establish a natural hierarchical organization of the shape description, combining region and boundary information and providing good topological control. This multiscale shape description is also numerically very fast. The work we have initiated in this direction relies on earlier work by Ogniewicz (at Harvard). While his work is mainly qualitative we have started research concerning quantifying the shape information in terms analogous to the classical wavelet-based smoothness descriptions of classical function spaces.

3.1.2 α shapes

As part of this initial effort we have implemented and studied several different numerical procedures for curvature driven flows. We have studied the use of so called alpha shapes, a rather simple-minded procedure developed at University of Illinois.

Another technique for generating solutions to nonlinear diffusion equations has been developed by Dziuk and by Polthier et al for mean curvature flows and discrete minimal surfaces. Their approach uses an iterative minimization procedure where, for each iterative step, the next surface is generated by parameterizing the offset from the old, previous surface; at each step a certain Dirichlet integral is minimized. This procedure linearizes the problem and significantly reduces numerical difficulties. This seems to provide a path to numerically efficient procedures for quantifying even highly complicated shapes. We have started the implementation of such a system.

3.1.3 Superresolution

A better understanding of shape information yields more robust and efficient methods for automatic classification of man-made objects, such as roads, targets, etc. Potentially it also allows us to recover details in image data that have been lost in the process of projecting into a finite resolution. This ability to obtain higher resolution in an image than provided by the sensor is called "super-resolution." We have investigated some simpler super-resolution procedures, such as feature driven interpolation, time-dependent sampling and three dimensional curvature flows, and compared these with standard magnification techniques such as pixel replication and bilinear interpolation.

3.2 3D-2D imaging

The 3D-2D imaging is a robust variant of the classical, ill-posed shape-from-shading problem. The approach we have developed as part of other efforts allows the reconstruction of three dimensional objects and surfaces from photographs (intensity image data). We have been investigating if these techniques can be improved in several ways. For example, we have investigated whether it is possible to obtain robust reconstructions using only two light sources and pertinent, auxiliary information. We have shown that this is indeed possible. We have also investigated how image information is translated into three dimensional features, and, more specifically, how discontinuities in the normal vector field of the three dimensional surface corresponds to features in the photographs. The intent is to continue this effort and develop new navigation techniques and new automatic target detection/reconstruction algorithms based on three dimensional object/surface descriptions.

3.3 Nonregular sampling

One of the problems partially solved by the 3D-2D imaging techniques is how to provide an autonomous or semi-autonomous system information about the full environment it operates in. For example, traditional sensors have an obvious directional dependence, which only provides a segment of the environment and in the spectrum of the sensor. The additional environmental information that can be obtained is particularly for highly dynamic situations such as collision avoidance, real-time mission

planning and landing of UAVs.

In addition to the 3D-2D techniques we have also started the investigation of nonregular sampling grids and image warping. By utilizing warping techniques we can obtain a full spherical view (4π steradians) of the airspace around the UAV. While this clearly in very attractive for the UAV's awareness, it poses a number of mathematical challenges. One approach is to first carry out the warping and then obtain an "regular" image defined on a square lattice. However, ideally, the image processing task should be carried out before warping. This reduces the numerical complexity and also avoids loss of resolution and small-size information. The investigations have started by first carrying out the warping, utilizing Coon's patches, and wavelet techniques. This will be extended to nonlinear approximation techniques on nonregular sampling lattices. An initial goal is to carry out object/motion detection before warping, and then obtain a gaze-based, very compact representation of the detected object/motion. This will be particularly important for setting up a highly effective collision avoidance system. The 4π view will also provide additional landing information.

4 Directions for Continued Research

The current phase sets us on a very ambitious path toward advancing identification of object in the context of a visual source aided by other physical information, such at attitude, field-of-view, velocity, within the overall system architecture associated with this project. Our next efforts will continue the definition phase of this project by investigating particular properties of objects in the information space based on the methods discussed in this report.